

DESIGN AND EVALUATION OF THE WORLDSID PROTOTYPE DUMMY

Risa Scherer, Dominique Cesari, Takahiko Uchimura, Greg Kostyniuk, Martin Page, Kazuhito Asakawa, Edmund Hautmann, Klaus Bortenschlager, Minouri Sakurai, Takeshi Harigae

WorldSID Tri-Chair Committee

Members of the WorldSID Task Group, Design Team and Project Manager

Paper Number #409

ABSTRACT

The WorldSID is a new, advanced **Worldwide Side Impact Dummy** that has the anthropometry of a mid-sized adult male. It has a mass of 77.3 kg, a standing height of 1753 mm and a seated height of 911 mm. Almost every body region is a new, innovative design, setting the WorldSID apart from all existing side impact dummies. It incorporates over 200 available data channels, in-dummy wiring, and an in-dummy data acquisition system (DAS). The dummy is designed to be used for research and future harmonized side impact test procedures as defined by the International Harmonized Research Activities (IHRA) and other organizations. It is expected to have a biofidelity classification of “good” to “excellent” using the International Organization for Standardization (ISO) dummy classification scale. The WorldSID will be the basis for the future development of a side impact dummy family. The WorldSID project is run under the auspices of the ISO working group on Anthropomorphic Test Devices -- ISO/TC22/SC12/WG5. Worldwide vehicle manufacturers and governmental bodies have sponsored its development. A design team of worldwide dummy manufacturers, instrumentation manufacturers and research organizations was formed to design, develop and fabricate the prototype.

This paper will provide the general design requirements for the WorldSID dummy and a description of each of the critical body regions. A description of the unique instrumentation found in the WorldSID dummy and the data from the biofidelity testing conducted to date will also be presented.

BACKGROUND

In November 1997, the WorldSID Task Group was formed under the auspices of the International Organization for Standardization (ISO) TC22/SC12/WG5 - Anthropomorphic Test Devices Working Group [1]. The Task Group’s purpose was to develop a unique, technologically advanced side impact dummy. This dummy is intended to be a more biofidelic side impact dummy and to replace the current side impact dummies in regulation and other testing.

Currently, three mid-sized male side impact dummies are available for regulatory and development use. They are the DOT SID dummy, which is utilized in the United States Side Impact Protection regulation [2]; the Eurosid-1 dummy, which is regulated in a European standard [3]; and the Biosid dummy, which is available for developmental purposes. All three dummies have different levels of biofidelity. The SID, Eurosid-1 and Biosid dummies have each been rated using the ISO biofidelity scale that provides classifications as seen below in Table 1 [4]. The SID has a ISO biofidelity classification of “unacceptable”, the Eurosid-1 has a classification of “marginal” and the Biosid has a classification of “fair”. The three dummies are structurally different, have different instrumentation and associated injury assessment criteria. Partially because of these reasons, and the differences in the test procedures, these dummies typically provide different design direction to the vehicle development engineer

Table 1.
ISO Biofidelity Classifications

Excellent	> 8.6 to 10.0
Good	> 6.5 to 8.6
Fair	> 4.4 to 6.5
Marginal	> 2.6 to 4.4
Unacceptable	0 to 2.6

The vision of ISO was to develop a harmonized dummy that would have technological buy-in from biomechanics, dummy and regulatory experts from around the world. To accomplish this, the Task Group was charged with developing the dummy’s specifications, its design, and finally with fabricating and evaluating the prototype.

INTRODUCTION

The WorldSID Task Group reviewed all of the currently existing side impact dummies to determine what features should be incorporated into the new WorldSID dummy and what improvements were required. The group also entertained various proposals and ideas from worldwide dummy and instrumentation manufacturers and research organizations. An international design team was

formed to develop these new concepts and incorporate them with existing desirable features into an advanced side impact dummy. The majority of the dummy consists of new design concepts, with the exception of the neck, which is from the Eurosid-2 dummy.

The Task Group also assembled a list of specifications for the WorldSID dummy. This list consisted of general specifications for the full dummy assembly and specific specifications for the various regions of the dummy.

One of the general requirements for the dummy was that it be a symmetrical design. The Task Group decided that this was necessary because future uses of the dummy are unknown. It is speculated that the dummy may be required to measure occupant-to-occupant interaction in a side impact test. If this were required, the dummy would have to be capable of being instrumented simultaneously on both sides so that it could measure the impact from the impeding vehicle and the impact from its neighboring occupant.

Also because of the unknown nature of future testing requirements, the dummy is required to produce reasonable data for ± 30 degrees in the horizontal plane and ± 10 degrees in the vertical plane. This is to ensure that the dummy does not bind in an off-axis loading situation.

The dummy is also required to be capable of using an in-dummy data acquisition system (DAS). This was because of the large number of potential channels being specified. The large quantity of instrumentation would produce a large bundle of cables that would have to hook up to an in-vehicle DAS. This would make it difficult to properly position the dummy. So, the group thought it was necessary to offer an optional in-dummy DAS.

The WorldSID dummy has over 200 possible data channels. The desire to provide detailed information in the various body regions of the WorldSID has resulted in this large quantity of data channels. The user, of course, would choose only the appropriate channels for his testing scenario.

The completed WorldSID prototype dummy is shown in **Figure 1**.

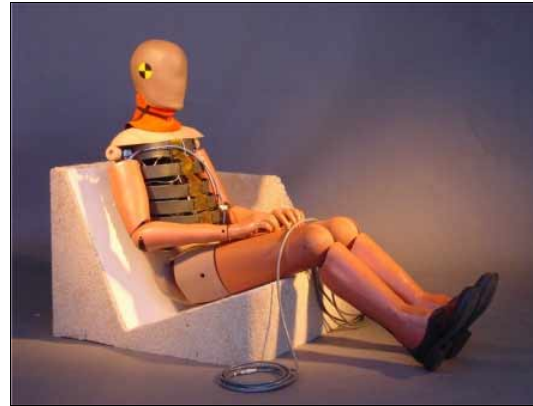


Figure 1. WorldSID Prototype.

WORLD SID PROTOTYPE DESCRIPTION AND INSTRUMENTATION

HEAD AND NECK

Technical Description

The WorldSID head is a completely new design (**Figure 2**). The head consists of a combined skull/skin assembly and an instrumentation core (**Figure 3**). The skull is fabricated from polyurethane and the skin, which is permanently attached to the skull, is PVC. The polyurethane skull is hollowed out so that the instrumentation core, constructed of aluminum, inserts into the head cavity.

The Task Group decided to have a featureless WorldSID face. The face is anatomically correct, minus the ears, nose and lips. One design criteria was for the head to be seamless because the Task Group was concerned that the dummy's head may impact the interior of the vehicle at a seam in the head and possible air bag entrapment, which may skew the test results. Since this was a requirement, the instrumentation core inserts from the base of the head and is secured by a bolt that comes down from the top of the head. This is a feature different from other side impact dummies.

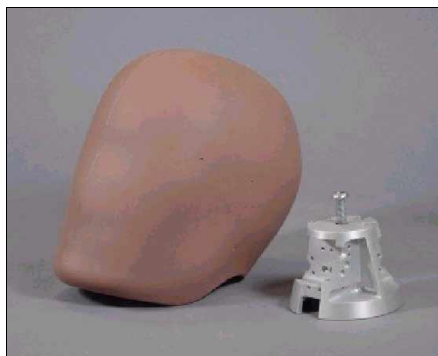


Figure 2. WorldSID head.

The WorldSID neck (**Figure 4.**) is adopted from the Eurosid-2 dummy. The neck is constructed of a rubber column with aluminum adapter plates on both the top and bottom. Both adapter plates mount to 6-axis neck load cells. Unlike previous side impact dummies, the WorldSID has an adjustable neck. The neck can be rotated rearward about the y-axis 9° and forward 27° from its neutral axis when in the proper seating position.



Figure 4. Neck.

The head and neck of the WorldSID dummy are not only intended to be biofidelic in the lateral direction, but also in the frontal direction. Biofidelity in both directions is needed because of the potential for off-axis loading of the head and neck. Off-axis loading can occur in pure side impacts, side airbag evaluations, and future test scenarios. To accomplish this objective, it was necessary to change the fore-aft spherical rubber buffers (used in the Eurosid-2 design) to a square buffer design. The rubber buffer configuration can be seen in **Figure 5.**



Figure 5. Neck buffers.

Also, a neck shroud (**Figure 6.**) has been developed for the WorldSID to prevent air bag entrapment. This shroud is expected to have minimal effect on neck response and we recommend that it (or any future improved shroud) be used whenever there is a possibility of an airbag contacting the dummy's neck area.



Figure 6. Neck shroud and shoulder skin.

Instrumentation

The head instrumentation, mounted on the core, consists of a triaxial accelerometer located at the head center of gravity, three rotational accelerometers, also located at the head center of gravity, and two tilt sensors (**Figure 7.**). The tilt sensors are static devices and are intended to be used for proper positioning of the head prior to testing.

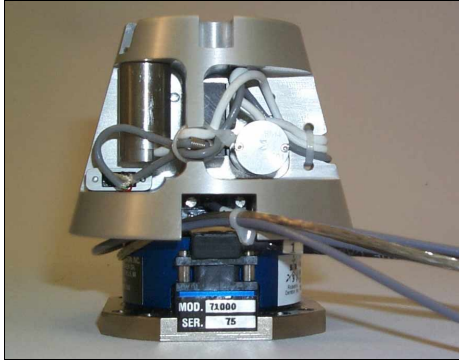


Figure 7. Instrumentation core.

The neck instrumentation consists of two six-axis load cells. The upper neck load cell mounts to the head instrumentation core and the lower neck load cell mounts to the neck adjustment bracket.

SHOULDER AND ARM

Technical Description

A unique rib assembly represents the shoulder of the WorldSID dummy (**Figure 8.**). Each shoulder rib unit consists of two bands of a super-elastic alloy, Nitinol™. The inner band is circular and the outer band is approximately shaped to the human surface. The outer band attaches to the rear of the spine box and wraps in front of the arm joint where it attaches to a rod to represent the clavicle. The shoulder rib has damping material on the inner band to control the deflection rate. The shoulder rib is inclined to induce an upward and forward motion of the shoulder joint as it is deflected laterally. The maximum deflection of the shoulder rib is 75 mm. Since the WorldSID is a symmetrical design, both the left and right shoulder ribs are identical. Since the shoulder is represented by a rib design, it is necessary to include a foam shoulder skin that sits on top of the rib, to provide the correct anthropometry (**Figure 6.**). The skin is held in place by the suit.

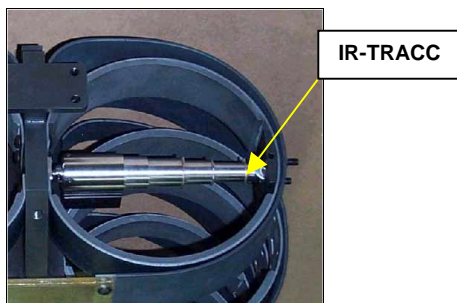


Figure 8. Shoulder Rib and IR-TRACC.

The WorldSID dummy has two different available arm configuration: a stub upper arm similar to the EUROSID-1 arm (**Figure 9.**) and a full arm (**Figure 10.**). In both the full and half arm, a bulbous pad on the upper arm at the shoulder level is used to control the initial impact spike in lateral loading of the shoulder to better match the biofidelity response targets. The intent of the full arm is to be used to measure air bag loading in static testing and the half arm to be used in dynamic testing situations, similar to the SID-II's dummy.



Figure 9. Half Arm.



Figure 10. Full Arm.

Instrumentation

Shoulder deflection is measured with an InfraRed Telescoping Rod for Assessment of Chest Compression (IR-TRACC) (**Figure 8.**) [5].

Irregardless of which arm is used, a shoulder load cell is located on the impacted side of the dummy where it can measure loads along 3-axe: Fx, Fy, and Fz. These measurements could be important to help evaluate airbag designs that can contact the arm during deployment -- especially if deployment from the seat back or B-pillar areas. For the half arm, the humerus bone simulation also contains two triaxial accelerometers -- one near the shoulder and one near the elbow -- to help resolve the forces and kinematics when struck by a forward-deploying seat-mounted

side airbag, or a forward- or rearward-deploying door-mounted side airbag. It is complete with 6-axis upper and lower arm load cells, a 2-axis elbow load cell (Mx, My), an elbow rotation potentiometer and triaxial accelerometers at the elbow and wrist.

THORAX AND ABDOMEN

Technical Description

The thorax and abdomen assembly is comprised of a series of rib units, individually attached to a rigid spine box. Each rib unit is oriented horizontally to the vehicle X-Y plane, except for the upper thoracic rib. It is inclined approximately 7 degrees to the horizontal and has a smaller anterior/posterior section than the other thoracic and abdominal ribs. All the rib units are constructed of a dual band structure identical to the shoulder rib. Each of these rib units is constructed of Nitinol™ and the inner bands have a Hybrid III-type damping material bonded to them to control the deflection rate. Each rib unit has a maximum deflection capability of 75 mm

The thorax is comprised of three rib units and the abdomen is comprised of two units. The thorax rib units are bridged to each other and the shoulder by a plastic sternum plate. A similar plastic sternum plate attaches the abdomen rib units to each other. The shoulder/thorax/abdomen assembly can be seen in **Figure 11**.

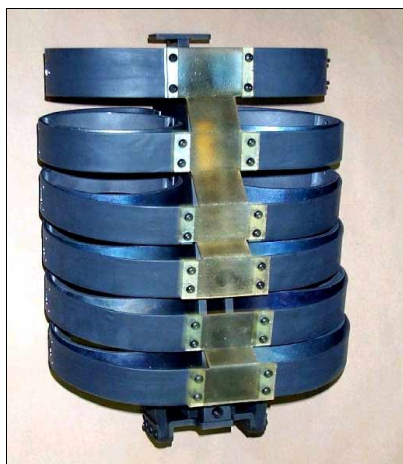


Figure 11. WorldSID Shoulder/Thorax/Abdomen assembly.

Instrumentation

Each rib is instrumented with triaxial accelerometers on the inside of the outboard ends of the rib units. Triaxial accelerometers are also located in the

proximity of the T1, T4 and T12 locations along the spine box. Two rotational accelerometers are mounted on the spine box, measuring about the X- and Y-axis. Two tilt sensors are mounted to the spine box to measure pre-test orientations of the spine box about the X- and Y-axis. Each rib can also be equipped with an IR-TRACC unit to measure deflection. The IR-TRACC measurement devices are gimbal mounted to the spine box and connected at the outboard end of the rib unit with a rose joint. Also mounted in the spine box of the WorldSID torso are two 32-channel DAS units. This is pictured in **Figure 12**.



Figure 12. Upper Torso DAS units.

LUMBAR SPINE

Technical Description

The WorldSID lumbar spine is a unique and innovative component, water-cut from one piece of solid rubber. It consists of an inverted U-shaped shell with two internal vertical stiffeners. The U-shaped shell controls the lateral rigidity and flexibility of the lumbar spine. The Task Group speculated that existing side impact dummies exhibit excessive load transfer between the upper and lower torso and wanted to reduce this in the WorldSID by softening the lumbar region. The two internal vertical stiffeners attach to the top of the spine only and are used to help support the dummy in a vehicle seat posture, but do not hinder the lateral flexibility. The lumbar spine can be seen in **Figure 13**.



Figure 13. Lumbar spine.

Instrumentation

The lumbar spine mounts directly onto a 6-channel lumbar spine load cell. Because of packaging constraints, this 6-channel lumbar load cell also incorporates the left and right 6-channel sacro-iliac load cells (**Figure 14**).

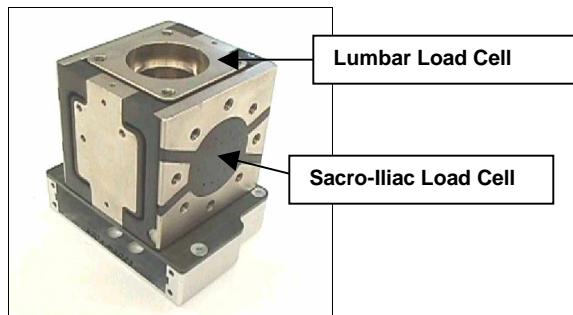


Figure 14. Lumbar/Sacro-Iliac Load Cell.

PELVIS

Technical Description

The pelvis consists of a conical shaped polyurethane pelvic bone that mimics the human pelvic bone. The major landmarks of the WorldSID dummy are close to the anatomical data. A vinyl skin surrounds the pelvic bone and this skin is filled with an elastomer. The hip joint of the WorldSID dummy consists of a ball and socket joint, this is a different configuration from the existing side impact dummies which all have hyme joint construction. The pelvis can be seen in **Figure 15**.



Figure 15. Pelvis bone and skin.

Instrumentation

The pelvis has a tri-axial accelerometer mounted at its center of gravity. A 6-channel pubic symphysis load cell connects both sides of the pubic bone. As previously mentioned, the pelvis also contains an 18-channel lumbar/sacro-iliac load cell and contains a left and a right 6-channel femoral neck load cell. The pelvis also includes two tilt sensors that are to be used for pre-test positioning. Also packaged in the pelvis is one 32-channel DAS box.

LOWER EXTREMITIES

Technical Description

The lower extremities are unique to the WorldSID dummy. The legs are fully instrumented from femurs to ankles. The lower leg design uses a similar ankle assembly to the Thor dummy. The legs are hollow tubes covered with foam filled vinyl flesh. The leg flesh is split on the inboard side so that it provides easy access to the instrumentation cables and for ease of installation. The dummy has molded shoes on its feet. The complete leg assembly is shown in **Figure 16**.



Figure 16. Complete leg assembly.

Instrumentation

Each leg is instrumented with universal 6-axis leg load cells. The load cells were design with the ability to mount anywhere in the leg assembly. These load cells can be located in the upper femur, lower femur, upper tibia, and lower tibia. The knees also have single axis load cells located at the inboard and outboard side of each knee measuring lateral loads. The inversion/eversion and flexion rotations of the ankle are also measured by potentiometers. Also included in each leg is two 32-channel DAS systems. So each leg houses 64 channels of data acquisitions system. The structure of the leg is shown in shown in **Figure 17**.

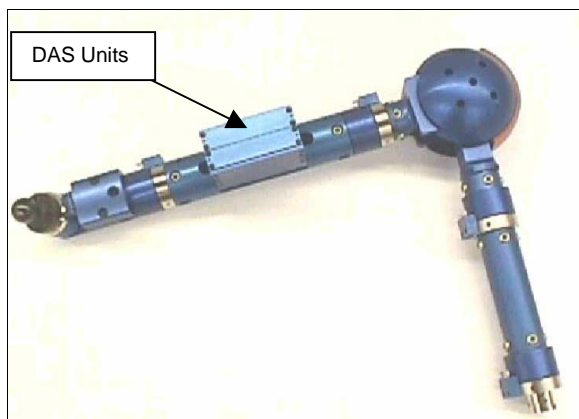


Figure 17. Instrumented leg with DAS.

WORLD SID RESPONSE TARGETS AND PERFORMANCE

The WorldSID prototype dummy has been evaluated using the procedures and targets specified in ISO Technical Report 9790 – Lateral Response Requirements to Assess the Biofidelity of the Dummy [4]. These targets have been derived from the responses of cadavers and volunteers subjected to lateral pendulum impacts, drop tests and sled impacts. These tests assess the biofidelity of the WorldSID prototype as a human surrogate for lateral impact testing.

The data presented is an initial biofidelity evaluation of the WorldSID prototype dummy. The initial testing data will be used to tune the dummy, as needed, to achieves a “good” to “excellent” ISO classification for all regions of the dummy.

HEAD AND NECK PERFORMANCE

For the evaluation of the lateral biofidelity of the head, the head is dropped from a 200 mm height onto a rigid surface with an accelerometer located on the non-impacted side of the head in line with the head center of gravity. The setup is shown in **Figure 18**.



Figure 18. Head drop configuration.

The WorldSID head has been tested three times on both the left and right side. The left side head drop and right side head drop data are presented below in **Figures 19 and 20**, respectively. Head center of gravity data are presented. Because the WorldSID head is of a solid construction this made it impossible to mount accelerometers on the opposite side of the impact area of the head. The data need to be translated to represent the data on the opposite side of the head, as opposed to the data at the center of gravity. The data have been presented just to show that the head has a symmetrical response.

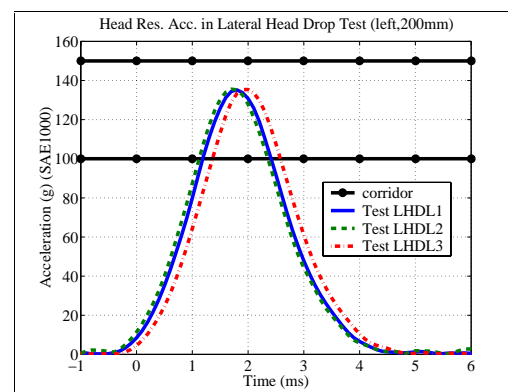


Figure 19. Left side Lateral Head Drop data. (at C.G.)

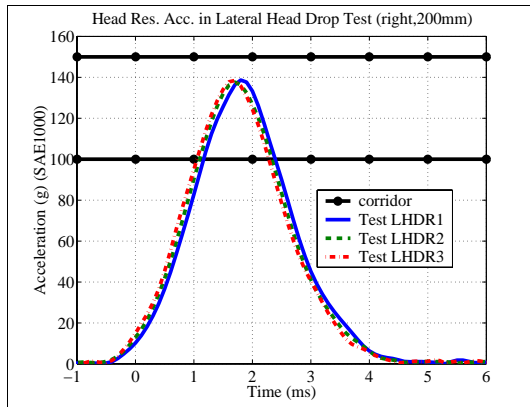


Figure 20. Right side Lateral Head Drop data. (at C.G.)

The WorldSID head was also tested in the frontal mode[6]. Three repeat tests were conducted in this mode. The results of the frontal head biofidelity are below in **Figure 21**.

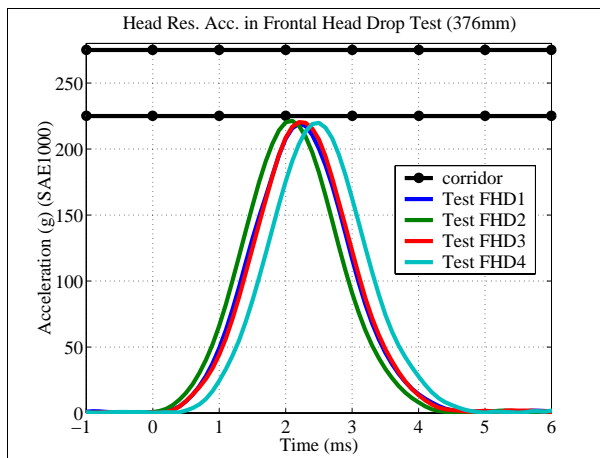


Figure 21. Frontal Head Drop data.

The neck lateral biofidelity tests are sled tests. At the time of writing this paper, the sled portion of the prototype evaluation had not begun. This will be the subject of a future paper. It is also the intent of the Task Group to evaluate the neck for biofidelity in flexion and extension. These tests also have yet to be conducted.

SHOULDER PERFORMANCE

The WorldSID shoulder was subjected to a lateral pendulum biofidelity test which consists of impacting the shoulder, with the arm down, using a 23 kg, 150 mm diameter rigid pendulum impactor at 4.5 m/s. The pendulum force data are shown in **Figure 22** and the shoulder displacement data are shown in **Figure 23**.

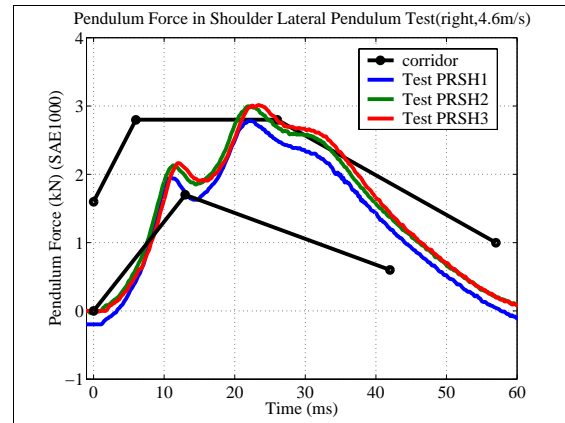


Figure 22. Shoulder pendulum force.

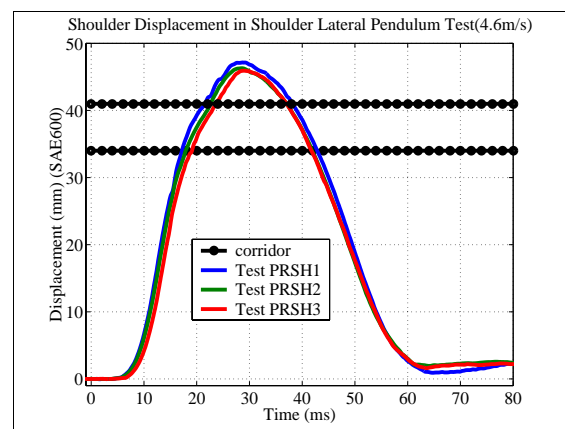


Figure 23. Shoulder deflection.

Three additional shoulder tests are required to determine the shoulder biofidelity of the WorldSID. These tests are sled tests and have yet to be conducted. They will be presented in a future paper.

THORAX PERFORMANCE

The WorldSID thorax was subjected to two different lateral pendulum biofidelity tests consisting of impacting the thoracic ribs, with the arm 90 degrees forward from vertical, using a 23 kg, 150 mm diameter rigid pendulum impactor at 4.3 m/s and 6.7 m/s (**Figure 24**). The pendulum and T1 acceleration data from the 4.3 m/s pendulum impact are in **Figure 25** and **26**, respectively. The pendulum data from the 6.7 m/s pendulum impact are **Figure 27**.

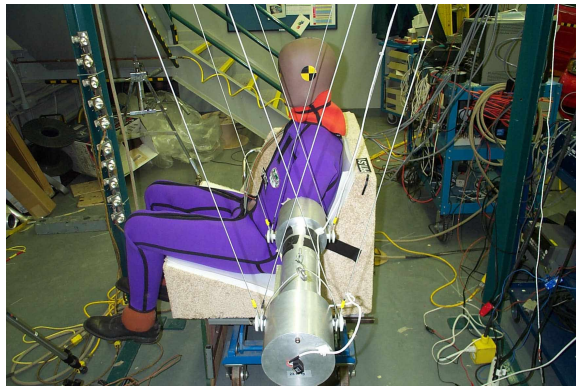


Figure 24. Thorax Pendulum Impact Test set up.

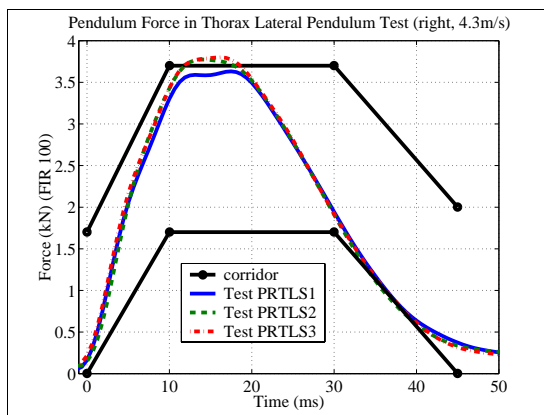


Figure 25. 4.3 m/s Thorax Test Pendulum Force.

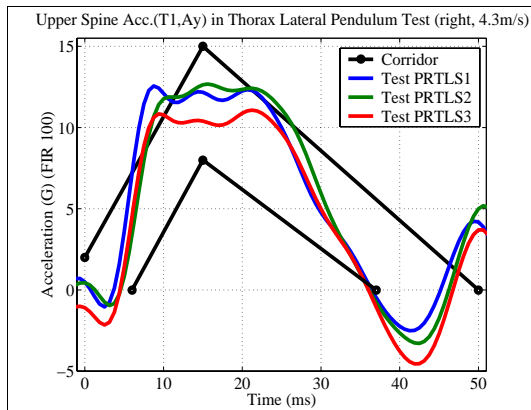


Figure 26. 4.3 m/s Thorax Pendulum Test T1 Accelerations.

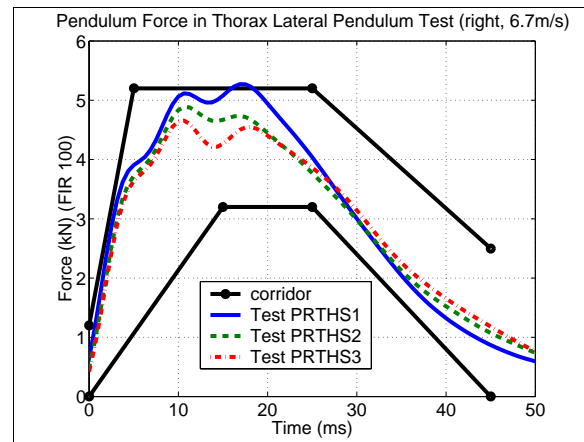


Figure 27. 6.7 m/s Thorax Pendulum Impact pendulum force.

Three additional thorax tests are required to determine the overall thorax biofidelity of the WorldSID. These tests consists of a 1.0 m rigid drop test and two different sled tests. All three tests have not been conducted at the writing of this paper. They will be the subjects of a future paper.

ABDOMEN PERFORMANCE

Two abdominal drop tests are required to determine the overall biofidelity of the WorldSID abdomen. At the time this paper was written these tests had not yet been conducted. The results will be subject to a future paper.

PELVIS PERFORMANCE

The WorldSID pelvis was subjected to a lateral pendulum biofidelity test consisting of impacting the pelvis with an 17.3 kg rigid impactor at 6.0 m/s. The pendulum force data from the 6.0 m/s pendulum impacts are in **Figure 28**.

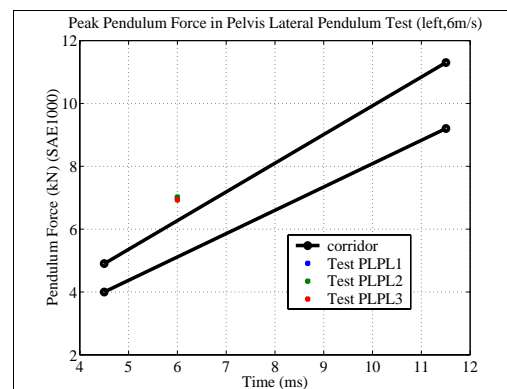


Figure 28. Lateral Pendulum Impact – pendulum force.

The WorldSID pelvis was also subjected to a 1 m lateral drop test. This test consists of dropping the dummy laterally from a height of 1 m onto two rigid plates. One plate spans the shoulder, thorax and abdomen regions and the second plate spans the pelvis region (**Figure 29.**). The arm is rotated 20 degrees forward of the dummy's thoracic spine. The pelvis acceleration data for the 1 m drop test are in **Figure 30.**

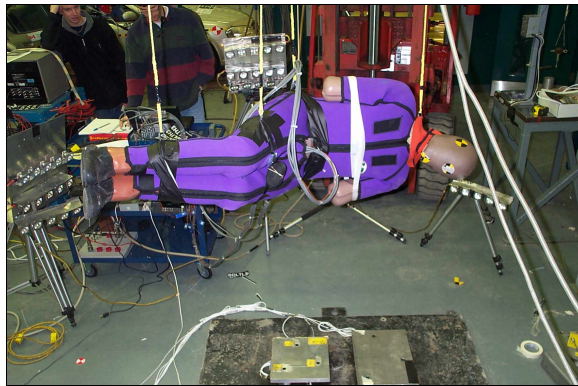


Figure 29. 1 m Pelvis Drop Test Configuration.

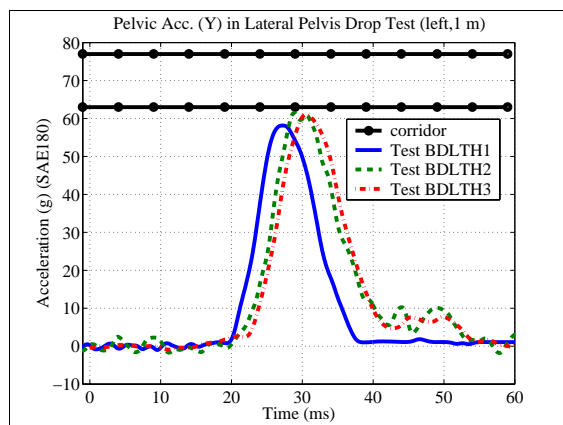


Figure 30. 1 m Pelvis Drop Test.

Eight additional pelvis tests are required to determine the overall pelvis biofidelity of the WorldSID. These tests consists of a 11.5 m/s pendulum impact, 0.5 m rigid drop test, four different rigid sled tests and two different padded sled tests. All eight tests have not been conducted at the writing of this paper. They will be the subjects of a future paper.

OBSERVATIONS AND CONCLUSIONS

This paper presents an initial glimpse of the biofidelity of the WorldSID prototype dummy. The WorldSID prototype is the first of its kind and will be subjected to upgrades based on the results of this biofidelity testing and the near future biofidelity

testing. The WorldSID prototype is in the initial portion of its evaluation.

Based on the responses presented in this paper the following observations have been made:

- 1) The lateral head response is symmetrical.
- 2) The frontal head response needs a little tuning to achieve its target response.
- 3) The WorldSID prototype shoulder is too soft.
- 4) The thorax meets the corridors at the 6.7 m/s test, but could use some fine-tuning to meet the 4.3 m/s response.
- 5) The 6.0 m/s pelvis pendulum impact tests indicate that the localized impacted region of the pelvis may be too stiff. The 1.0 m pelvis drop tests seems to show that the overall pelvis region may be slightly too soft. This issue requires further investigation and resolution before the WorldSID dummy is production ready.

This initial testing has indicated that the performance of the WorldSID prototype is directionally correct. However, further improvements are required to achieve the Task Group objective of developing a side impact dummy with an ISO classification of “good” to “excellent”.

ACKNOWLEDGEMENTS

The WorldSID Task Group would like to thank the WorldSID Design Team for all of their hours of effort and dedication to make the WorldSID prototype become a reality.

The Task Group would also like to thank Transport Canada for sponsoring the pendulum and drop tests. We would also like to acknowledge PMG Technologies for their dedication to the WorldSID evaluation.

The Task Group is grateful to Lan Xu for expediently generating all the data plots for this paper and for the editing capabilities of Agnes Kim.

REFERENCES

1. ISO/TC22/SC12/WG5 N542, 36th Meeting, November 5-6, 1997, Orlando, Resolution 1.

2. Federal Motor Vehicle Safety Standard MVSS 214 – Side Impact Protection, 49 Code of Federal Regulations, Part 571.
3. Directive 96/27/EC – Side Impact Resistance of Motor Vehicle, May 20, 1996.
4. ISO/TC22/SC12/WG5, Technical Report 9790 – Road Vehicles – Anthropomorphic Side Impact Dummy – Lateral Impact Response Requirements to Assess the Biofidelity of the Dummy, 2000.
5. S.W. Rouhana, A.M. Elhagediab, and J.J.Chapp, “A High-Speed Sensor for Measuring Chest Deflection in Crash Test Dummies”, ESV 98S9015, 1998.
6. Hybrid III: First Human-like Crash Test Dummy, Edited by Backaitis and Mertz, SAE PT-44, 1994.